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IMPORTANCE OF 4D IN BIM FOR AN EFFECTIVE CONSTRUCTION PLANNING

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ABSTRACT

The integration of 4D technology (3D + time) in the BIM for a better project planning is the core of the present work. After analyzing their general theoretical requirements, the different possibilities of 4D BIM tools as well as the required are assessed, paying special attention to the opportunities and limitations. The workflow from the practical part is completed with the use of the following software: Autodesk Revit ® 2014, Microsoft ® Office Project 2013 and Autodesk Navis works Manage ® 2013. These tools, which allow implementing the BIM methodology, turn out to be really useful to satisfy and facilitate many of the project management functions, both in the planning and construction phase. Furthermore, they are a perfect platform for a collaborative and transparent environment. The opportunity to visualize and simulate the construction process is the key to reduce the aforementioned project risks. At the same time, resistance to change is an important barrier to encounter in the adoption process. This is the reason why it is really important to understand the framework in which these tools must be implemented, because the combination of ideas incorporated by all these concepts could result essential. After all, all of them look towards a common goal: improving the construction sector.

Keywords:*BIM, 4D, productivity, planning, scheduling, visualization,*

1. INTRODUCTION TO BIM

One of the most promising developments which the architecture, engineering andconstruction industries have achieved in the past few years is Building Information Modeling (BIM). BIM is used to construct virtual models of a building digitally. These computer generated models contain accurate geometrical data of the building components and other necessary data needed to support the fabrication, construction and procurement activities. BIM also contains several of the functions required to model the lifecycle of a building, providing the platform for new design and construction capabilities. When efficiently utilized, BIM facilitates a more integrated design and construction process which results in high quality of buildings at reduced project duration and lower cost (Eastman, Teicholz, Sacks, & Liston, 2011). BuildingSMART (2010) defines BIM as follows: "The building information model (BIM) is a set of information that is structured in such a way that the data can be shared. A BIM is a digital model of a building in which information about a project is stored. It can be 3D, 4D (integrating time) or even 5D (including cost) – right up to 'nD' (a term that covers any other information)."BIM aims at improving collaboration between stakeholders (see Figure 0-6), reducing the time needed for documentation of the project and producing more predictableproject outcomes.

2. DIMENSIONS OF BIM

Apart from traditional drafting software AutoCAD which provides the 2D design of building, BIM provides three more dimensions that is, 3D, 4D and 5D, where 3D is three dimensional Space; 4D adds time as a dimension; and 5D includes cost as a dimension.

a) 3D BIM

3D BIM contains all the spatial relationships, geographic information and geometrye.g., length, width, and height of the

building components. By the use of virtual 3D building model, design errors due to inconsistent 2D drawing are identified and eliminated. In addition to this, models from different disciplines can be brought together and compared to check for any conflicts and constructability problems before they are identified on the construction site. By the implementation of 3D building model the coordination among different project participants is enhanced and errors are significantly reduced. This leads to an efficient construction process with reduced costand minimized likelihood of legal disputes.

b) 4D BIM

The addition of the time attribute to a *3D* (x,y,z*)* environment results in what it is broadlyknown as *4D* (x,y,z,t)environment. This extra feature provides the model with more dynamism in terms of representing the behaviour of the building elements along time, extending in this way its usage for other purposes. In principle, BIM and 4D technology are separate concepts and have had different progression from their conception. Nevertheless, it is believed that their combination in the same working methodology could help enhance certain processes and it seems especially interesting for contractors (Eastman et al., 2011). 4D tools allow planners to visually communicate and plan activities in the context of time and space. This makes possible the adoption of alternative approaches to site layout, scheduling and planning during the construction phase. 4D BIM requires linking construction plan to the 3D model, which makes possible to visualize how the building and site would look like at any point in time by simulation the construction process.

c) 5D BIM

5D BIM requires project cost to be integrated with the 3D model of the buildingmaking it possible to forecast and track the project cost throughout all the phases ofconstruction. The use of BIM has two benefits. First, it can automatically produce accurate quantities, used for cost estimation. Second, it is possible to create an 'active' link between the design and corresponding costs so when the design changes, so will the estimate costs. When estimators use BIM in cost estimation, this also influences the estimating process. Therefore, BIM has changed the way QSs perform their duties and subsequently brings impact on the speed and efficiency of the professional services. By implementing BIM, QSs can improve their performance and productivity as these tedious tasks can be automated by BIM.

3. CONSTRUCTION PLANNING

Construction planning is an inevitable activity in effective management of any construction project. It involves tracingback from the result and identifying the sequences of events which lead to that result. This is a challenging job for the planner since the final outcomes of construction projects are not possible to observe until they are completed. Moreover, the inevitable nature of uncertainties and complexity of construction projects are also put together to create more intricate challenges for project team in accomplish construction planning. However, construction planning is not a process only limited in the period before construction's actual start; it should be considerably taken into account during the project life cycle and would require re-planning if something wrong should happen. Not only can an effective and proper plan limit the possibility of problems occurrence, it also lessen the adverse consequences of such problems. The aim of planning is to generate required activities as well as their interdependence and thereby ensuring that the project will be completed as early as possible. Planners have to thoroughly analyze the sequences, the implementation and also impacts of such various activities. Afterwards, based on the evaluation and experiences from previous projects, decisions will be made to determine what strategies and performance methods are the most beneficial. In other words, through construction planning, suitable technologies are selected; work tasks are assigned; resources are allocated and project participants as well as the interaction between them are identified.

4. PROJECT SCHEDULING IN BIM

Project scheduling (4D modeling) in BIM is to link a BIM model to a schedule tovisualize the schedule of the construction. The use of scheduling function in BIM (4D Model) can help the users establish optimized schedule of the project in a 3D environment which also allows the users to have a virtual view of the whole project. Construction planning involves scheduling and sequencing activities in time and space, taking in account resources, procurement, spatial constraints and other concerns in process. Traditionally, bar charts and Critical Path Method (CPM) scheduling are used to plan the construction activities. However, these methods do not consider the spatial configuration related to these activities and neither do they link these activities directly to the building model. Therefore, scheduling is an intensive manual job and it often does not synchronize completely with the design and makes it difficult for the project stakeholders to understand the schedule easily and its effect on the site logistics. To address these shortcomings in the planning process, 4D technology has evolved. Many commercial tools have evolved till now to facilitate the process of creating a 4D model with automatic links to 3D geometry or entities for
construction activities. 4D modeling allows the simulation and evaluation of the planned construction schedule. Grouping of the objects in the building model should be done according to the construction phases and linked to relevant activities in the construction schedule. 4D simulations for planning process acts as a communication tool for identifying potential bottlenecks and as method to improve collaboration among different project teams.

The design and the construction schedule can be synchronized by linking the building model to the project schedule. It allows users to simulate the construction process and show the virtual view of the building and the site. Construction planning is an ongoing effort to manage the progress of a construction project and react accordingly – dynamically adjusting to the "situation on the ground." Of course, a building's design is at the core of its project plan, and by adding schedule data to a 3D building information model (i.e., the building design) you can create a 4D building information model, where time is the 4th dimension. 4D models include planning data such as the start and end date of a component and their criticality or slack. As a result, a 4D building information model provides an intuitive interface for project team and other stakeholders to easily visualize the assembling of a building over time. It enables 4D construction simulation, a key planning tool during preconstruction to evaluate various options. 4D storyboards and animations make BIM a powerful communication tool – giving architects, builders, and their clients a shared understanding of project status, milestones, responsibilities, and construction plans. Teams usually start out developing 4D models by *manually* mapping the schedule dates from the project plan to the model components. That effort helps them improve the plan and improve how they communicate the plan to the whole team. Later, as they advance their skills, they *programmatically* link the schedule to the model, to save time and increase their ability to evaluate various construction sequence options. A building modelled in Revit can be exported to Naviswork manage, a software developed by Autodesk which support Revit files and helps in generating schedule of activities modelled in BIM by providing the start and finish dates of each activity according to levels.

4.1 MANUAL CAD-BASED METHODS

Colored pencils and drawings, with different colors to represent different sequences to show progress of work with time have been used by construction planners for decades. This process was shifted to CAD drawings by the planners with the advent of CAD. Planners worked with a third party to create rendered animations to visually present the schedule in most of the cases. These animations are very appealing visually and tend to be a very effective marketing tool, but they are an inadequate scheduling and planning tools. The main reason for this is the manual production of the animations with limited options to change, update, and do real

time scenario planning. With every change in schedule detail, the planner must create a new set of images or animations to manually resynchronize the 4D image with the schedule. Due to these limitations, the use of these tools is normally restricted to the initial stages of the design when visualizations of the construction process play an important role and is much desired by the clients (Eastman, Teicholz, Sacks, & Liston, 2011).

4.2 BIM TOOLS WITH 4D CAPABILITY

Another way to generate 4D images is through features that automatically filter the objects in the view on the bases of the parameters set. Revit is one such tool which distributes the objects into several phases according to the requirement. The user can then apply filters to view the desired object in a specific phase. This type of 4D functionality is applicable to basis phasing and generation of 4D images at desired requirements but does not provide direct integration with the project schedule. Whereas, Tekla Structures, a BIM tool, provides a built-in scheduling interface enabling multiple links between the physical objects and the activities in the model. A single physical object can be linked to one or several activities and a single activity can be linked with one and several physical objects making the 4D evaluation of construction sequence possible, with emergence and disappearance of temporary facilities. Most of the BIM tools, however, do not have built-in "time" or "date" capabilities, and require specific add-on tools or 4D modules to directly link to schedule data (Eastman, Teicholz, Sacks, & Liston, 2011).

4.3 EXPORT 3D BIM TO 4D TOOL AND IMPORT SCHEDULE

The limitations of previous BIM 4D method encouraged the software developers to find out a way which can fully integrate the scheduling function with the 3D model Generally, the steps involves importing the existing 3D BIM model into the BIM software tool, importing the schedule created by another scheduling software tool (such as PrimaveraTM and Microsoft Project™) and then linking the schedule with its relevant objects in the BIM model some BIM scheduling software tools may have the in-built function to define the schedule itself. Autodesk Navisworks™, ProjectWise Navigator™, Visual Simulation™, Synchro Professional™ and Tekla Structures™ are the object-based 4D tools, which mean the imported schedule will be linked to the objects of the building model. Vico Control™ is different from others; it is a quantity-based 4D scheduling tool. In order to calculate the schedule, Vico Control™ links the quantities of the building objects to a "recipe" that contains the description of materials, labor, resource, cost and even location information. Most of the 4D tools such as Autodesk Navisworks™ can provide users a virtual viewof the building and site. The schedule which is defined by the in-built scheduling function in Navisworks™, is linked to the building components in the 3D building model, and this integration of 3D model and project schedule is called 4D model. The benefits of this integration are: The 4D model can produce a visual representation of time, show the project status, provide the virtual simulation of the project and even provide views of physical completion of building at various points in time. Contractors can communicate with other stakeholders and coordinate the expected time and space flow based on the simulated project process. By providing the simulation in the 4D environment, contractors can ensure that the plan is feasible and efficient (Eastman *et al.* 2008).This integration allows the real-time project process to be updated morefrequently. The process of the project can be updated automatically according to the change in the building design (Hwang *et al.* 2010). Contractors can arrange the site logistics based on the virtual 4D simulation such as arrange lay-down areas, location of equipment, *etc.*

5. 4D BIM IN PROJECT LIFE CYCLE

4D models have several uses throughout the whole project life cycle and they offeropportunities within different project phases. 4 different stages can be distinguished

regarding possible utilization of 4D models to assist construction projects: (1) pre-design stage, (2) design development, (3) tendering phase and (4) construction stage.

a) Pre-design stage:at very early design or drafting stages, 4D technology is useful for the analysis of possible construction alternatives. It allows comparing several solutions with the interaction between the basic construction schedule and very general parts of the building, such as levels and spaces, but not at the element level yet.

b) Design development:as the design advances on and more details are to be included, this technology is valuable to carry out constructability analysis. Whilst project planning attains importance, 4D models are truly helpful to check whether the planned schedule and construction sequence make sense. Apart from that, they are of good use to compare and select construction methods and processes.

c) Tendering phase:4D models can be used by contractors to communicate the different construction phases to the client, as well as the way in which the building is to be constructed. In part it could serve to convince the client about the ability of the general contractor to carry out the project. Therefore, 4D technology would not only work as a selling tool, but also to gain accuracy in the estimation by means of a better understanding of the construction sequence.

d) Construction stage:during the construction stage one of the challenges for contractors is to coordinate trades or subcontractors on site so as to avoid time space conflicts. This is another capability of 4D models along with the help they provide for visual site management. Another utility for this stage would be the 'as builtvs. as-planned'comparisons for project monitoring functions. Hence, the use of 4D can be extended to work as a tool to improve field productivity through an enhanced coordination and communication between disciplines and project participants. Regardless of the project phase, there is no doubt that these 4D models enhance project understanding, particularly in those large-scale projects with especially high complexity. Logically, the requirements of the model would significantly vary depending upon its purpose. If the model is to be used as a mere visualization tool, for instance, to show a construction sequence to the client in an animated manner the information and scheduling criteria used for such animation would not be vital. Nevertheless, if it is going to be used for management purposes by contractors and project managers, the model would be much more demanding in order to satisfy the flexibility needs of planners. This is the key factor where BIM has something new to offer.

6. UTILITIES OF 4D MODELS

After reviewing the existing literature on the evolution of 4D applications one can expectseveral functions to be covered by up-to-date 4D technology. The real value of 4D planning is an issue aim of debate among practitioners, since the client is several times considered to be the only beneficiary of all this, rather than planners. Nevertheless, this is not what literature suggests, because 4D BIM is referred to as a new dimension set to achieve more ambitious objectives. Briefly summarizing the content, these are some of the theoretical utilities of 4D models when they are to be used as an aid for project management functions

1) SCHEDULE VISUALIZATION:one of the most common utilities of 4D models is theirimplementation for visualizing construction sequences. As an extra attribute introduced to 3D models, time visualization can considerably facilitate the understanding of schedules, not only to planners, but also to the rest of the team or stakeholders. This feature encourages the collaboration of all the participants, achieving a high level of transparency, which is demonstrated to be vital.Schedule

visualization is not limited to the design stage, but it also serves during the construction stage, for instance, for visualizing the changes introduced in a construction schedule. Time schedules can be visualized by means of either snapshots or simulation clips. Finally, real-time navigation at any construction stage via *3D walk-through* or *fly-through* is another possibility of 4D models.

2) 4D SIMULATIONS:Simulating the construction process is a visual way to assessconstructability and to get close to the real conditions in the building site prior the start of site works. In other words, 4D simulations could serve as a sort of construction *rehearsal* to reduce uncertainty and anticipate project risks. They are applicable to entire projects or to a certain period of time, e.g., structural works phase. Sometimes creating a clip can be more effective than having snapshots in order to more evidently reflect the dynamism of a building site. Actually, animations can be included to make even more visual for everyone.

3) INTEGRATION AND COMMUNICATION OF PROJECT PARTICIPANTS:

4D technologies arealso proper to be used in project meetings as a perfect mean for collaboration. It has been mentioned that effective communication between different trades and disciplines is vital during the construction phase. At the time of visualizing traditional construction schedules it is not rare to obtain different interpretations by different project members (Koo & Fischer, 2000. Thus, the addition of a visual component to the schedule is likely to help clarify any possible doubt as much as achieve a better communication and coordination among participants.

4) DECISION-MAKING:The construction practice involves constantly making decisions during design, planning and construction stages of a project. However, the solution is not always clear and sometimes quick decisions are taken blindly without being completely sure of the best and most suitable option. 4D models are a mean to assist decision-making of practitioners whenever they need a clear picture to discard or approve different options. It is known that those decisions taken early have the largest impact on the project (Koo & Fischer, 2000). Analyzing construction or schedule alternatives are some of the main decision utilities of these systems. Many scientific papers agree on the fact that 4D is above all a tool to make proper decisions.

5) RE-PLANNING:As they can be used for planning, 4D models can also be utilized for changing the schedule whenever it is required, in order to redirect the project towards the proper target. Flexibility to introduce these changes is vital so as to have a smooth flow and not to have to spend excessive time doing so (Chau et al., 2003 & 2004). Otherwise, if every time a change is to be made large amount of time would be required, 4D technologies would not have much sense. After all, neither the geometry nor the schedule is definitive from the beginning to the end. Consequently, the idea is rather to continuously be able to change and update the model until the end of the project.

6) TIME MONITORING: Control over completed tasks as well as those tasks underdevelopment is another important function of project management practises. Tracking the progress of the planned activities is imperative to know whether the plan is being accomplished and, in case it is not, to adopt proper measures to successfully confront the situation. Comparison of the *'as-planned'* against *'as built'*conditions is the key aspect of time monitoring. The use of visual mechanisms like colours can serve as a temporary tool to help monitor the time constraint in a more visible way.

7) ANALYSIS:Finally, 4D models can be used for carrying out analysis of different nature, all of them being related to project management activities. These are some of the alternative uses of these technologies:

8) CONFLICT DETECTIONS: Improper activity sequencing can originate time-space conflicts while carrying out construction works. This is usual because of the lack of visual content of time schedules. Foreseeing possible conflicts would

avoid problems in the building site, such as, waiting time and waste. The automated generation of workspaces to anticipate time-space conflicts or *bottlenecks*is another function that can be added to 4D models.

9) SITE UTILIZATION: 4D models can provide a dynamic picture of the space required in the building site during the different construction phases . Visualizing the location of resources like machinery, temporary equipment and installations or even possible spaces with stacked material of the utilization of the building site. Furthermore, the behavior of mobile equipment could be foreseen.

10) RESOURCE ALLOCATION: In order to know the resources (labor, material and equipment) required per activity 4D models can integrate functions to ease their optimum allocation. As studies analyzing these possibilities suggest, this would be obtained by means of a database providing such information.

11) HEALTH & SAFETY MANAGEMENT: Since health and safety measures are also part of the scheduled activities, 4D BIM can be useful for safety management.

CONCLUSION

Although they were devised separately, 4D (3D + time) technologies and the BIMmethodology can be benefited the one from the other by their combination resulting in the 4D BIM environment. It can have several uses but its validity for project management functions is to be checked in the present study. From an extensive literature review on 4D CAD it was learnt some of the functions expected from 4D tools. In this way, the mainrequirements of 4D BIM tools for project management functions are outlined for the assessment part of the study. Some other extra features are also recommendable to be included by the same tools. Among the different 4D BIM applications available, the one provided by Autodesk is going to be used for the practical part: Navisworks Manage 2013. One important concept is the fact that paper-based documentation and 4D do not go together, since it is much more visual to present a movie, instead of a picture. The more interaction with the 4D model the users have, the more information can be obtained. Finally, innovative solutions may arise in a not too distant future to help obtaining more 'active'functionalities by the incorporation of more automation in all the process.

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